TECHNICAL REPORT NO. LWL-CR-09M71

ROUGH TERRAIN GROUND HANDLING SYSTEM FOR HELICOPTERS

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April 1974

Final Report

Contract No. DAAD05-68-C-0366

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U. S. ARMY LAND WARFARE LABORATORY
Aberdeen Proving Ground, Maryland 21005

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER TECHNICAL REPORT NO. LWL-CR-09M71	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ROUGH TERRAIN GROUND HANDLING SYSTEM FOR HELICOPTERS		5. TYPE OF REPORT & PERIOD COVERED Final Report 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) E. Kisielowski K. Korsak P. Kubicki		8. CONTRACT OR GRANT NUMBER(s) Contract DAAD05-68-C-0366
9. PERFORMING ORGANIZATION NAME AND ADDRESS Dynasciences Corporation Bluebell, PA		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS LWL Task 09-M-71
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Land Warfare Laboratory Aberdeen Proving Ground, MD 21005		12. REPORT DATE April 1974 13. NUMBER OF PAGES 48
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Helicopter Handling
Tracked Unit
Ground Movement of Helicopters

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The need to move helicopters from their landing point to a place of concealment or more appropriate parking spot, was first stated, by the 4th Armored Division in Europe. Since 1970 USA Land Warfare Laboratory has been involved in a number of tasks associated with the ground movement of helicopters - these have involved hardware designed and built to demonstrate both the potential and problems of various means of handling skid mounted helicopters in rough terrain.

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BLOCK 20. ABSTRACT CON'T
The Rough Terrain Ground Handling System for Skid Mounted Helicopters is but one of these pieces of hardware.

The hardware will consist of two self-powered track units, and a cross structure to support the helicopter. The unit will pick the helicopter up by the standard ground handling wheel pickup points. It is sized for UH-1 helicopters.

One test unit is being fabricated under contract by Barnes and Reinecke, Inc., Chicago, Ill. The unit will be delivered to the Aviation Systems Command, St. Louis, MO. for evaluation and test.

PREFACE

The need to move helicopters from their landing point into a place of concealment or more appropriate parking spot was first conveyed to USA Land Warfare Laboratory (LWL) in November 1970 by the 4th Armored Division in Europe through an LWL Liaison Team. At that time LWL initiated a study into the feasibility of moving skid mounted helicopters over rough terrain.

This report covers the design study, and the detailed design of the system recommended by the study. At the time of the writing of this report, one test unit is being fabricated by Barnes and Reinecke Inc., Chicago, ILL. under contract to LWL. Due to the disestablishment of LWL on 30 June 1974, the hardware will be delivered to the Aviation Systems Command for evaluation and test prior to shipment to FT Hood, TX for field testing by Modern Army Selected System Test Evaluation and Review (MASSTER). The tests at MASSTER will be a part of Test No. FM 161 "Helicopter Ground Movement Systems", and the test results will appear in the final report on that task.

AD-778758

TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

In some areas of operation it is often required to move helicopters on unprepared terrain adjacent to or into the tree line for concealment purposes. The present ground handling gear is designed primarily for hard runway surfaces and is therefore inadequate for off-runway operations on soft and irregular terrain.

The objective of this study, performed under Contract No. DAAD05-68-C-0366, LWL Task 09-M-71, was to investigate the feasibility of, and to design, a simple off-runway handling gear for skid-mounted helicopters of the UH-1 type.

As part of this study, eleven different design configurations were considered within the limitations of the design criteria presented. Although, all of these configurations are considered feasible, further trade-off study involving complexity, weight, cost, and performance of each configuration is required to arrive at the optimum design.

Based on the engineering data accumulated, the most suitable configuration for off-runway operations was selected and a detailed design developed.

FEASIBILITY STUDY

Design Criteria

The following design criteria were used as a guide in the feasibility study of an off-runway handling gear for skid-mounted US Army helicopters.

Military Characteristics

Requirement: Provide US Army units with the capability of pushing or pulling helicopters across rough terrain and maneuvering them rapidly into and out of tree lines so that they could be easily concealed from aerial view and camouflaged.

Operations & Organization Concepts:

1. Operational Concept. Aviation units would use this item as part of their ground support equipment. It would be transported to the site either by vehicle or by aircraft.

2. Organizational Concept. It is envisioned that this item would be available through normal supply channels for the class of supply and would be issued on a basis of one per certain number of aircraft or size of unit.

Justification: Reason for the Requirement: The Ground Handling Kit currently used consists of wheels which raise the skids. The system can only be used with difficulty on rough terrain since there is very little ground clearance and a high ground pressure. A rough terrain system which would permit rapid easy movement of helicopters around on rough terrain and into and out of tree lines does not exist.

Characteristics:

1. Performance Characteristics.

a. (Essential) The device should be rugged and capable of moving a helicopter safely over rough terrain to include wet and dry plowed ground and grass grown areas (minimum cone index 40) and to negotiate 15 inch deep ditches or holes without a requirement for digging or disturbing the soil.

b. Number of major components. (Desired) 1.

c. Maximum weight: (Essential) Must be capable of being loaded/off-loaded from a vehicle by two to four men by manpower alone.

d. Maximum Size/Transportability: (Essential) Must require a minimum of space to transport/store and be transportable on a 3/4 ton truck and a UH-1 helicopter as an interior and exterior load. (Desired) Items should have the capability of being nested or stacked when more than one is transported at a time.

e. Environmental Requirement: (Essential) Climatic Categories 2 thru 7 (AR 70-38).

f. Paradrop: (Desired) yes.

g. Maximum Assemble/Disassemble Time:

(1) Preparation for use from transported mode by two men. (Essential) 15 minutes.

(2) Loading/Unloading helicopter by two men. (Essential) 1 minute: (Desired) 1/2 minute.

h. Performance Requirements:

(1) (Essential)Must be capable of moving the following helicopters: UH-1B, UH-1C, UH-1D, UH-1H, OH-58A, OH-6, AH-1G with laterial stability.

(2) (Essential) Require no more than the drawbar pull of ¼ ton vehicle to move a helicopter with it and be capable of being moved by vehicles up to and including 2½ ton in size. (Desired) 2 men.

(3) (Essential) Not place side loads on the skids of the helicopters being moved.

(4) (Essential) Must be capable of being maneuvered in order to guide the helicopter between trees and around obstacles.

2. Maintenance Concept. (Essential) Require little or no maintenance.

3. Human Engineering Characteristics. (Essential) Require no special training and be safe in operation in accordance with AR 602-1, dtd 4 March 1968 and AR 385-16, dtd 11 February 1967.

4. Priority of Characteristics. Performance, size weight.

Personnel Considerations: Introduction of this item into the Army inventory will require no additional spaces in TO&E of tactical units.

Design Data

1. The helicopter used as a model for this study was the UH-1 type with maximum gross weight of 9,500 lbs.

2. Maximum sinking of the skids into the ground during landing is 2 inches.

3. A single pass operation over a soil condition with a Cone Index of 40 was considered.

4. The propulsion system provides the off-runway handling gear with the capability to move the UH-1 type helicopter (10,000 lbs) over difficult

terrain at speeds from "just barely moving" to 2 miles/hr.

5. The complete off-runway handling gear system, including the propulsion system, will not weigh more than 1200 lbs.

6. The off-runway handling gear, complete with propulsion system, will be man-handleable consisting of components which can be manually loaded onto and from trucks and helicopters by a crew of not more than four men. No one component should weigh more than 300 lbs.

7. Adequate support to the skids is provided such that loads due to maneuvering or rough terrain are not transmitted to the skids in a direction not provided for in the skid design.

8. Minimum loading and unloading time of the helicopter was considered.

9. The design includes consideration of the following external stores attached to the helicopter:

a. Pod containing three SS-11 missiles mounted on side of the helicopter.

b. Pod containing two XM-76 Machine Guns.

c. Pod containing twenty-four 2.75 inches rockets, mounted on each side of the helicopter.

d. Two pods, one containing 7.62 mm Minigun and the other seven 2.75 inches rockets, mounted on each side of the helicopter.

e. Auxiliary fuel tank pods, one on each side of the helicopter.

f. Cargo hood underneath the fuselage.

Configurations

One of the prime design factors in this feasibility study was consideration of geometry, and location of the external stores relative to the model helicopter. A review of the external stores indicates that any one type of these stores may occupy a space between fuselage stations 70 and 160, outwards as far as butt-line 120 and downwards to the level of this fuselage floor. Hence to avoid obstruction and damage of the stores or the ground handling gear, this space cannot be occupied by any portion of the gear.

Furthermore, there are several methods of supporting the helicopter on the gear. One of the methods is to use the four existing fuselage jacking points or hard points. In this design approach, the loads due to handling of the helicopter over rough terrain are transmitted directly to the fuselage hard points, thus avoiding any possible damage to the skids.

In the second approach, the helicopter can be supported by the skids provided that the skid structure is reinforced. This is accomplished by introducing a cross-member joining the skids.

The third design approach of the ground handling gear involves a cart-type vehicle or a wheeled platform which would permit direct helicopter take-offs and landings. The cart can be designed so as to absorb handling loads over rough terrain and can be made essentially universally applied for a variety of helicopters of the same class.

Configuration 1a (Ref. Figure 1)

The off-runway handling gear as shown in Figure 1 is a single-piece unit supported on two front wheels 48" diameter, and 4 rear wheels 16" diameter. In this configuration the helicopter is fully supported at the jacking points, and it can be transported on the gear without requiring additional balancing.

The gear is equipped with a hydraulic system which can lift the helicopter 18 inches, providing a large ground clearance.

The basic structure is composed of a cross-member and of two fore-and-aft members, effectively forming a tee which carries the loads from four jacking points to the point where the wheel arms and hydraulic actuators are hinged.

The front wheel arms are rotable in vertical planes, and are controlled by hydraulic actuators. Lifting and lowering of the helicopter which rests on the basic structure is accomplished by the relative motion between the wheels and structure. A similar arrangement for raising and lowering the helicopter is provided at the rear arm. A buggy, carrying the rear wheels is hinged at the lower end of the arm so that it has freedom in pitch.

The hydraulic system is powered by two hand pumps, located near the front wheels. A hydraulic accumulator is installed which can be charged prior to actual operation of the gear. Control valves, located near the actuators are installed to allow individual operation of the actuators as required.

Alternatively, the hydraulic system may be replaced by a pneumatic system similar in operation to the hydraulic one, except that in this case the basic structure may provide an air reservoir which would replace the accumulator.

Available Goodyear Low Pressure, Flotation tires, size 48 x 20.00-16.1 are used for the front wheels. These are type "Super Terra Grip" (STG) designed for good traction. Since traction is not essential, these tires may be replaced by special "Smooth" (SM) or Rib (R) type which would be lighter. The rear wheels use available Goodyear Low Pressure tires, size 16 x 14.50-6, type "Rib" (R) which is ideal for this application. Both main wheels are equipped with hand operated parking brakes.

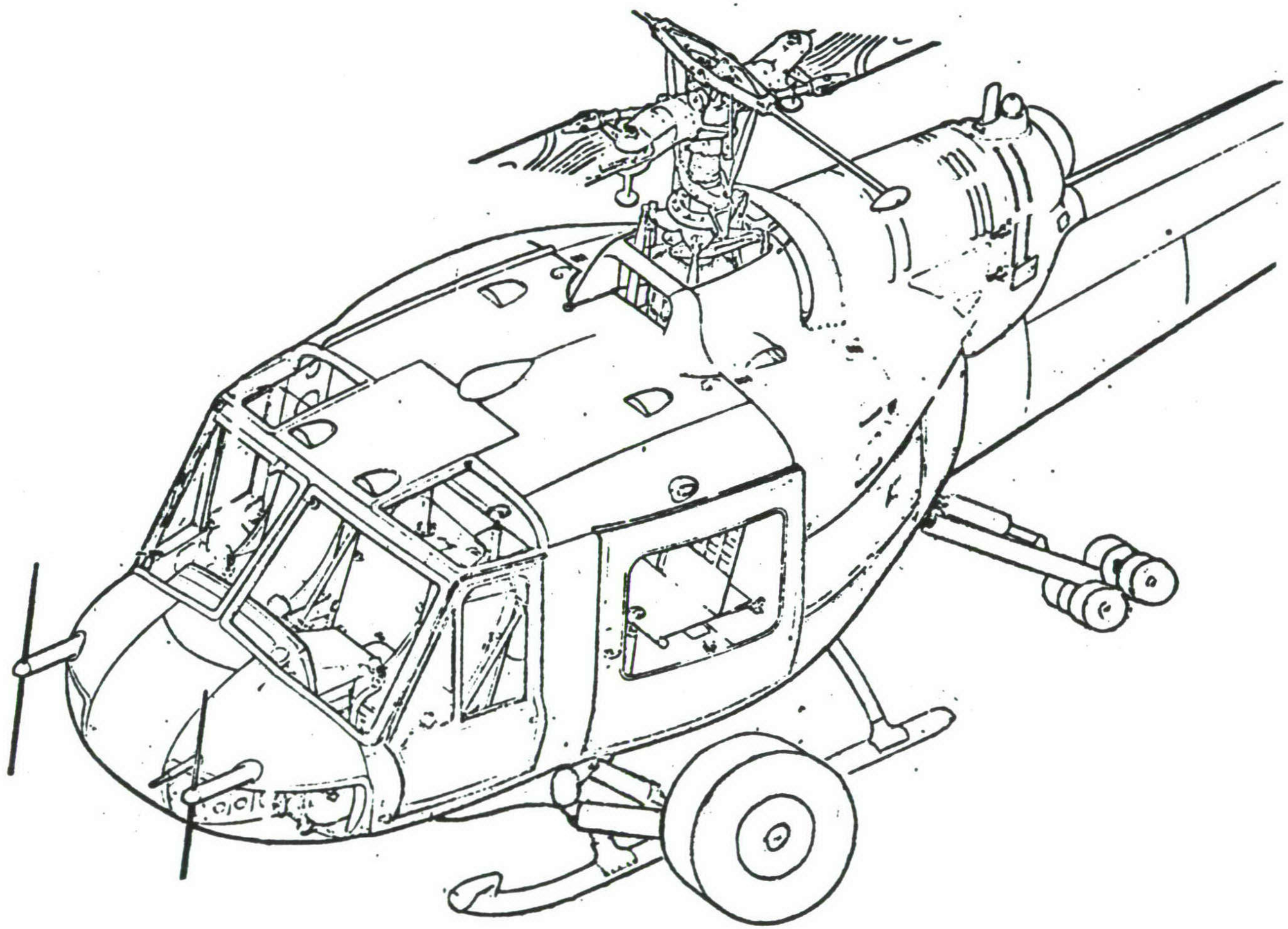

Figure 1. Off-Runway Handling Gear - Configuration 1a

With these tires, at Cone Index 40 and at helicopter gross weight of 9,500 lbs, the drawbar pull is estimated to be 760 lbs.

For transporting the gear the two fore-and-aft structural members can be made detachable from the remaining parts of the structure for ease of handling.

Operationally, the handling gear of this configuration has the advantage of being a one-piece unit assembled and ready to use when required. There is no need for any attachment of the gear to the helicopter. A pre-charged hydraulic or pneumatic system, together with other design features mentioned above allow quick loading transporting and unloading the helicopter under field operation conditions.

The disadvantage of this configuration is its large size and weight, and low "clearance" factor of the rear wheels (only .53 due to the small tire diameter). Clearance factor is defined as the ratio between the effective wheel radius, and the maximum obstacle, in this case a 15" deep ditch.

Configuration 1b (Ref. Figure 2)

This gear as shown in Figure 2 is similar to that of configuration 1a, with the exception that the rear wheel buggy is replaced by a track buggy. By doing so the "clearance" factor of the gear can be greatly improved, from .53 to .95.

While the development of a track buggy appears to be more costly, this configuration represents an improvement over configuration 1a.

Configuration 2a (Ref. Figure 3)

This configuration as shown in Figure 3 is a modification of configuration 1a, with exception that larger diameter tires are used. All tires are 48 x 20.00-16.1. With these tires, at a Cone Index 40 and at helicopter gross weight of 9,500 lb, the drawbar pull is reduced to 565 lb.

The gear is composed of two separate parts which are joined together when the gear is in place. In this configuration the helicopter is fully supported on its jacking points as in configurations 1a and 1b.

The gear is equipped with a single hydraulic system which operates four actuators. Functionally the system is identical with the hydraulic system provided in configuration 1a and 1b.

The basic structure is composed of two cross members, one for supporting the helicopter at its forward jacking points, and the other at its rear jacking points. The cross members are joined by two fore-and-aft members, one on each side of the helicopter. These members at their forward extremities are detachable from the forward cross member, to allow installation of the two parts of the gear without interfering with external stores and the skids. The two parts of the gear are joined to each other using a quick disconnect mechanism. The lifting arrangement is almost identical

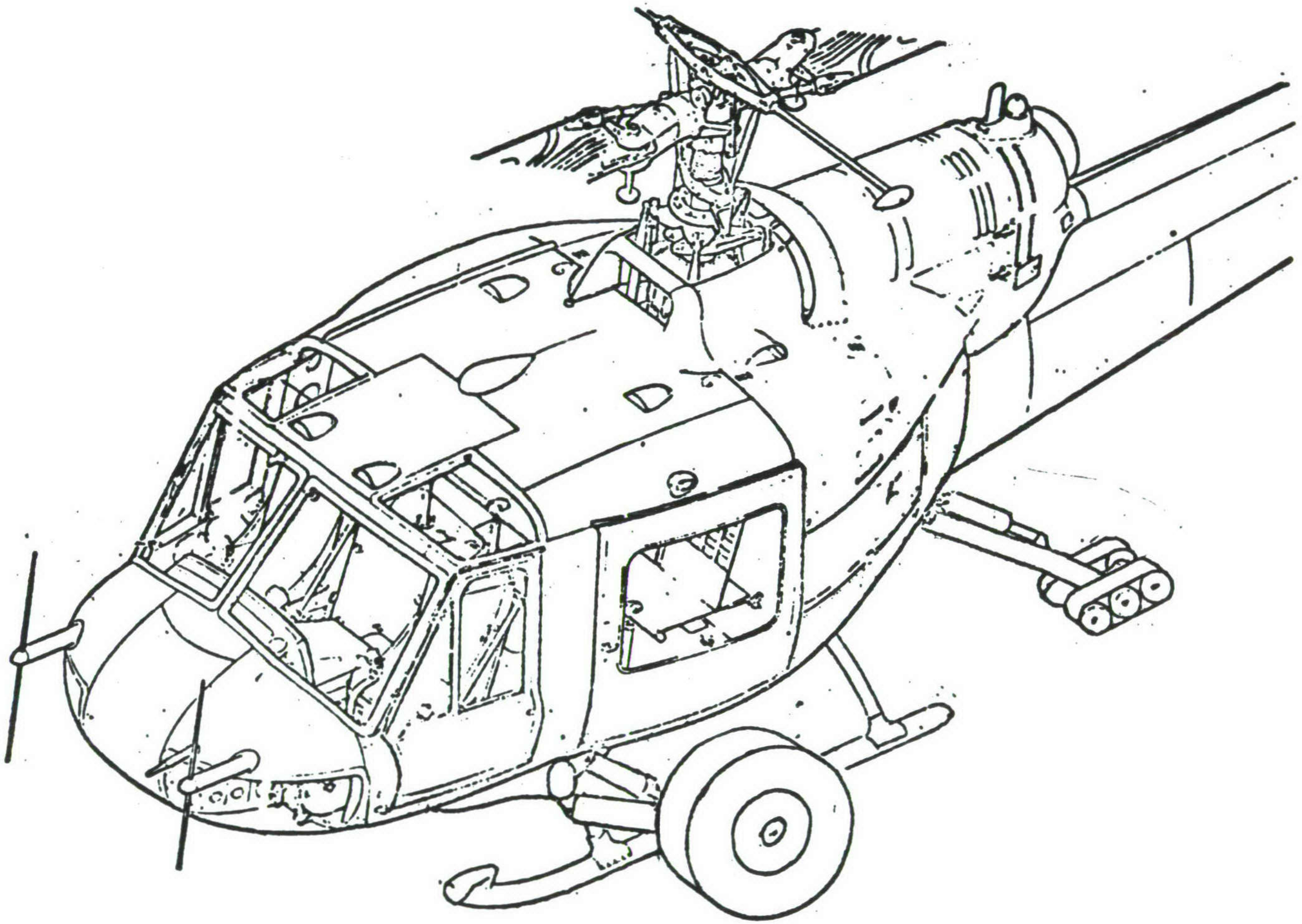

Figure 2. Off-Runway Handling Gear - Configuration 1b.

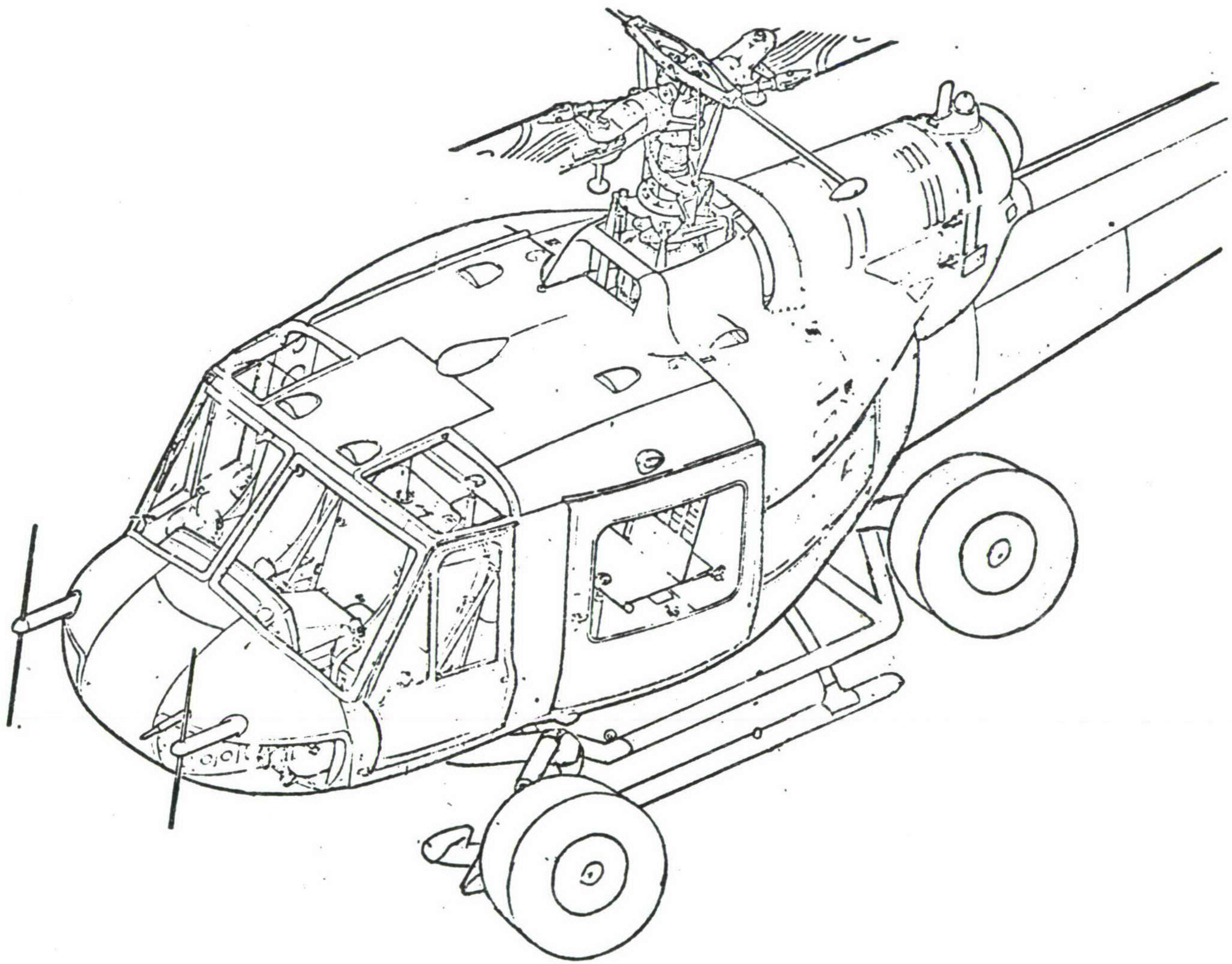

Figure 3. Off-Runway Handling Gear - Configuration 2a.

with that used in configuration 1a and 1b. The only difference in this arrangement is the quick disconnect coupling to join forward and aft portions of the hydraulic (pneumatic) system into one unit when the two pieces of the gear are structurally connected to each other.

By changing the arrangement from configuration 1 to configuration 2a, a considerable reduction (35%) in the drawbar pull can be achieved. However, the gear is more complicated in construction, heavier, and the time of installation and dismantling is longer - due to the necessity of connecting and dis-connecting the two parts of the gear. In addition, reliability is lower and the cost may be higher. As in the previous configurations the front wheels are equipped with hand-operated parking brakes.

Configuration 2b (Ref. Figure 3)

This configuration is identical to that of 2a, except that the tires are replaced by 38 x 20.00-16.1 tires which will fit on wheel discs of configuration 2a.

Due to this change, the weight of the gear is down by 180 lb, however the drawbar pull force is 12% higher.

Configuration 3 (Ref. Figure 4)

This configuration represents an attempt to utilize components of the Bell Kit No. 204-050-200-5, which consists of two separate units each equipped with two Type III aircraft tires 7.00-6, 8 ply, having 18" in diameter and 6.8" width and inflated to 54 psi. This kit at a cone index of 40 and at a helicopter gross weight of 9,500 lb requires a drawbar pull force of 2,600 lb (See Section IV) and as such appears to be unsatisfactory for operation in very soft terrain.

To reduce the drawbar pull force a variety of configurations were considered in which the Bell Kit tires were replaced by high flotation tires, tracks or tracks mounted between the skids. However, these configurations were rejected because of space limitations and clearance requirements between the gear and the fuselage, or the gear and external stores mounted on the fuselage.

One feasible design solution in which the Bell Kit components can be utilized is that represented by Confiquration 3 shown in Figure 4. In this case all necessary clearance requirements are met and the drawbar pull force can be reduced to an acceptable value of 565 lbs.

Configuration 3 consists of two track buggies cantilevered one on each side of the helicopter. The buggies have a sufficiently low profile to fit under the external stores.

The track of each buggy has a ground contact area of 400 in^2, which yields a ground contact pressure of 12.8 psi. In operation the gear performs similarly to the Bell Kit. It requires support of the helicopter at its tail to provide adequate equilibrium and maneuverability.

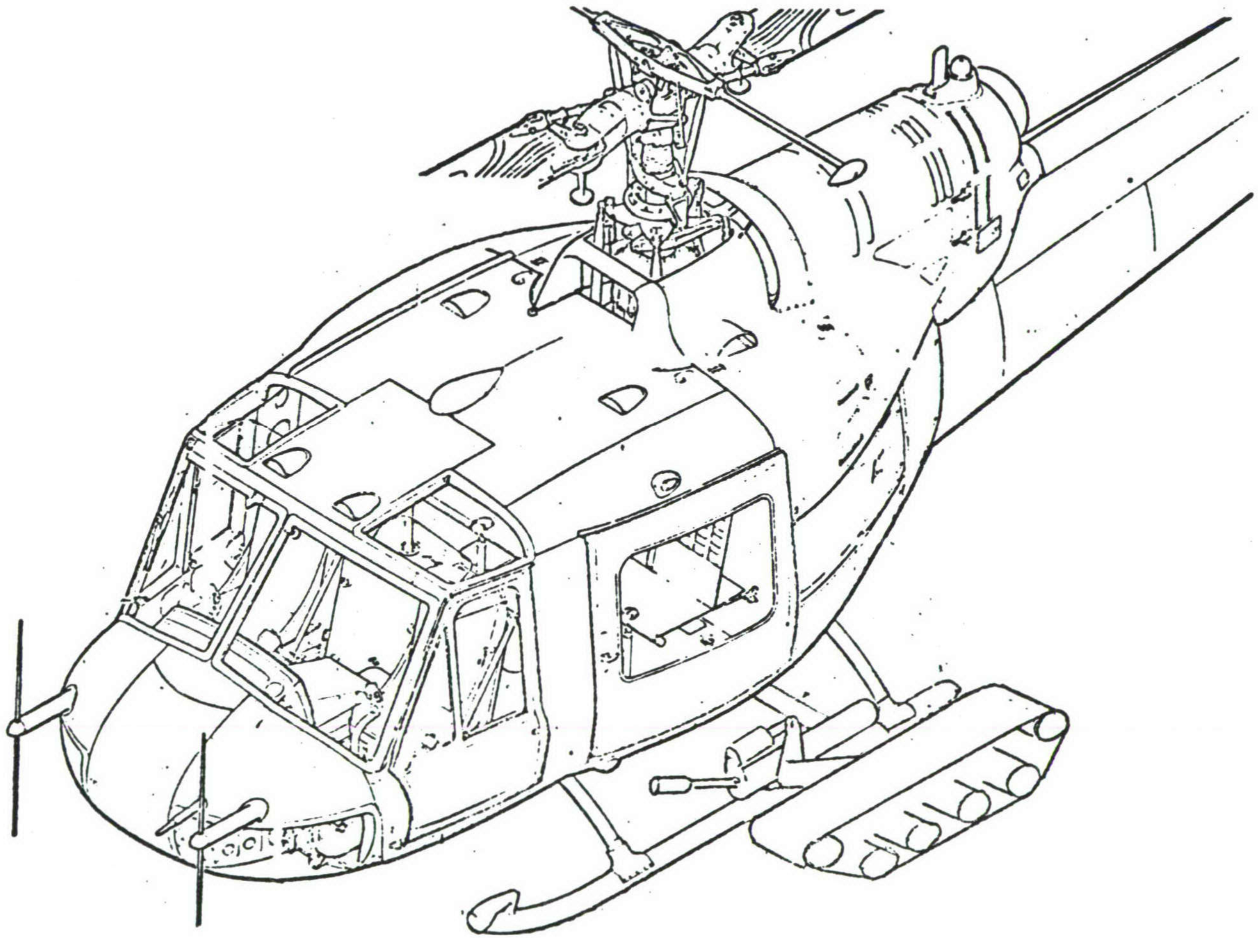

Figure 4. Off-Runway Handling Gear - Configuration 3.

The gear is in 3 parts: the left and right hand assemblies - attachable to the skids of the helicopter - and a cross member which is attachable to the left and right hand assemblies by means of quick-disconnect fittings. The structure of each, left and right assembly, consists of members which pick up two existing lugs on each helicopter skid and provide support for the buggy. The cross member joins these members structurally. It takes bending due to the vertical loads on the buggies - due to skidding of the tracks in maneuvers - and also provides a link between the skids to improve the structural integrity of the helicopter landing gear.

There are two separate hydraulic systems, each comprising a hand operated pump, an accumulator, an actuator and valves allowing quick raising of the helicopter for transport. Since the tracks cannot provide as much cushioning as the tires, the actuator has an air trap chamber to allow it to act as a shock absorber.

Alternatively, in lieu of hydraulics, a pneumatic system may be installed which then can use the structural member as an air reservoir.

Each buggy is hinged to allow freedom to pitch. The axis of rotation is located above the ground to provide adequate clearance of its supporting arm from the ground.

Configuration 4a (Ref. Figure 5)

This configuration, as shown in Figure 5,is identical to Configuration 3 except for the wheel buggies replacing the track buggies. Configuration 4a has each buggy equipped with Goodyear Terra Tires 29 x 12.06-16.1 and its cantilever overhang is the same as that of the track buggy of Configuration 3.

Configuration 4b

This configuration is identical with Configuration 4a except for different, smaller diameter wheels, used in the buggies. These wheels are wider, hence the cantilever arms of vertical loads are larger, making the supporting structure somewhat heavier.

In comparison with 4a, this configuration requires smaller towbar pull forces to move the helicopter on soft but flat ground; however, the clearance factor is reduced and the weight of the gear is increased.

Configuration 5a (Ref. Figure 6)

This configuration as shown in Figure 6 forms a platform on which the helicopter can land and from which it can take-off. It is equipped with Goodyear "Terra" tires of the same size as those used in Configuration 2a, hence it has the same performance as that configuration.

The gear operates as a single unit, and it doesn't require any lifting mechanism. As shown in Figure 6, it is designed for UH-1 helicopters,

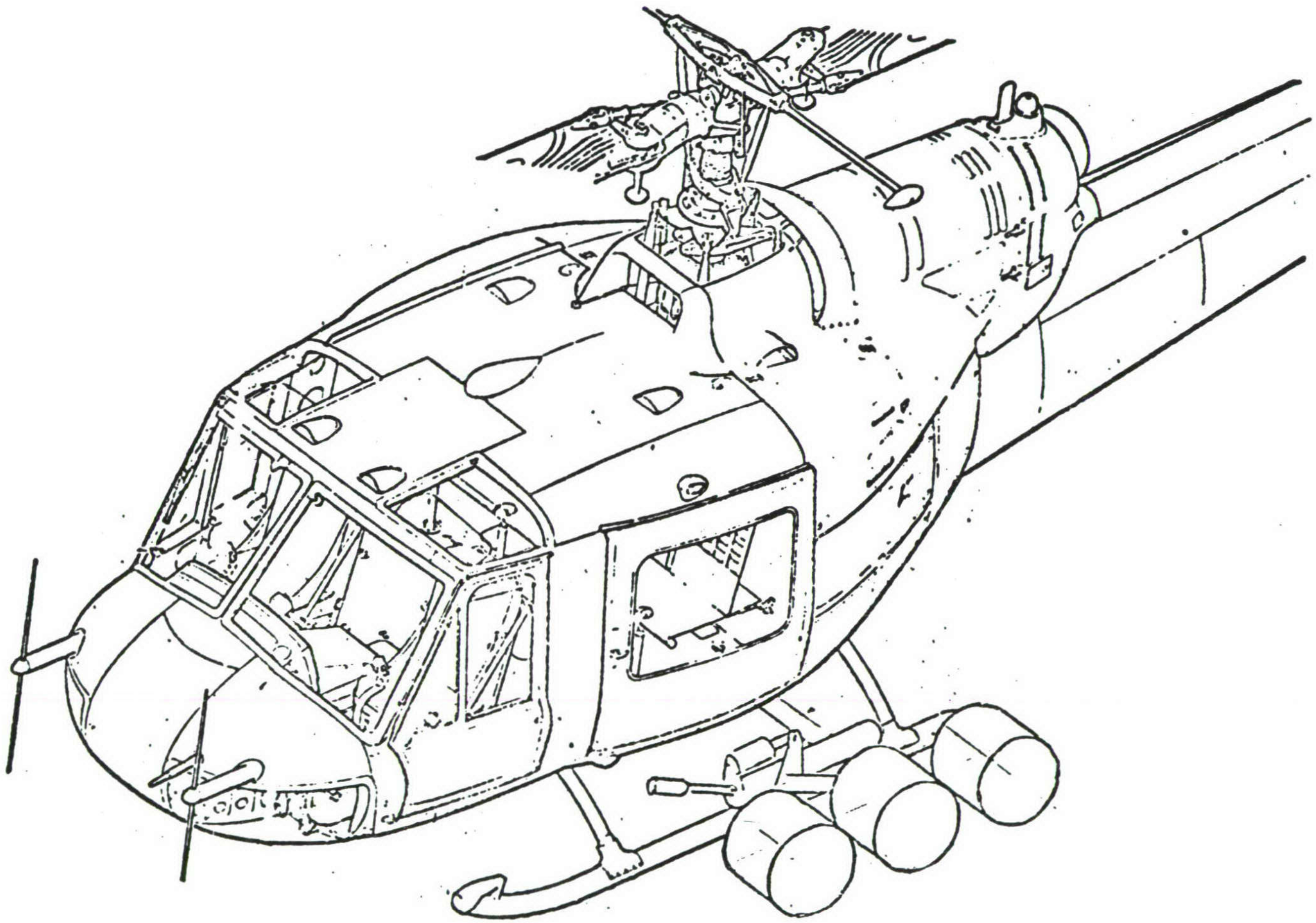

Figure 5. Off-Runway Handling Gear - Configuration 4a.

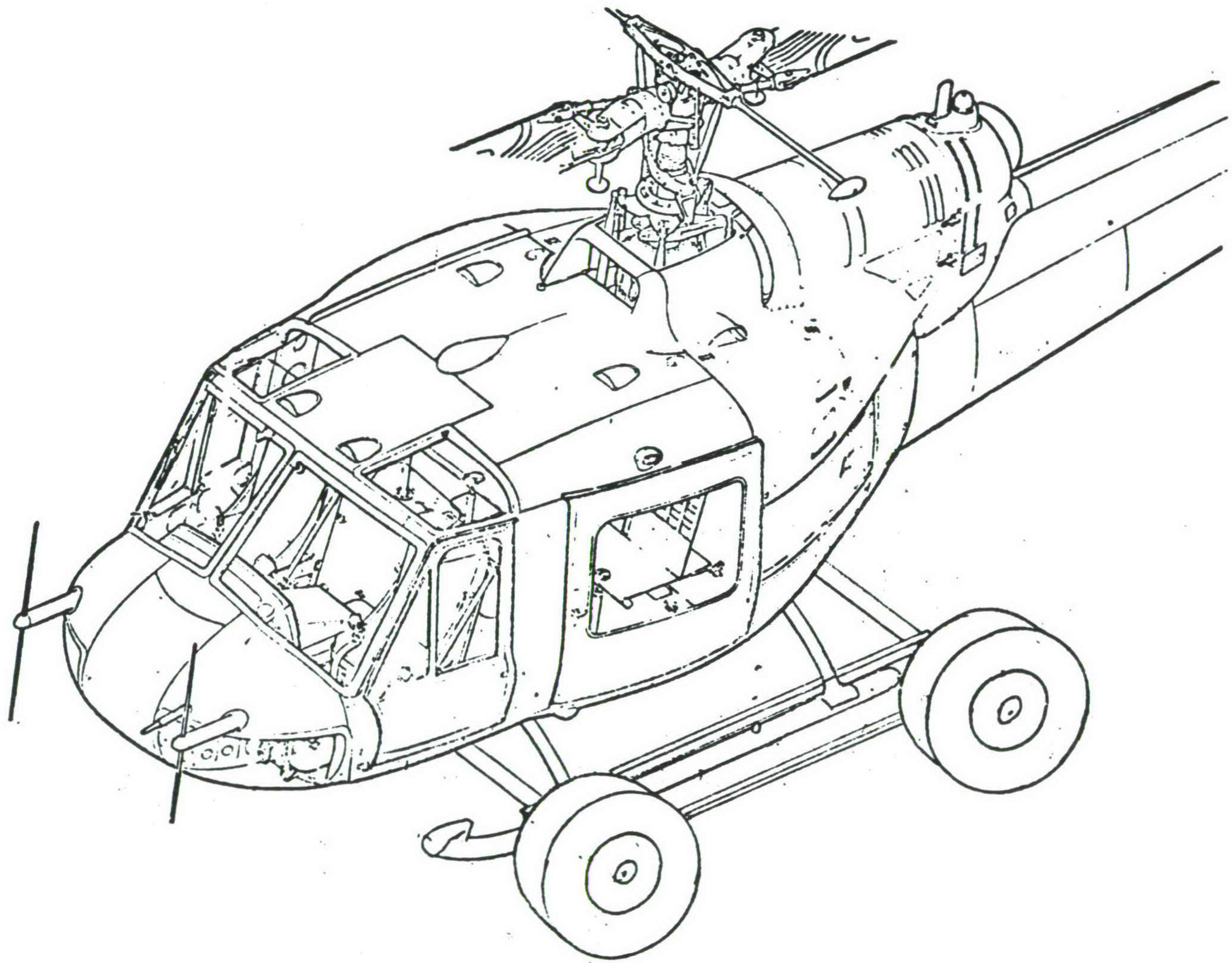

Figure 6. Off-Runway Handling Gear - Configuration 5a.

however the concept lends itself to provide a universal type of gear, suitable for all skid equipped and wheel equipped helicopters of a given range of gross weight, say up to 10,000 lb.

The structure consists of a rectangular frame, supporting the wheels which are located at each corner. The rear wheel axles attach directly to the frame. The front wheels are hinged for steering. The towbar picks up the front cross member of the frame and it steers the front wheels using push-pull rods.

This arrangement appears to be ideal for front line operation, as it would require a minimum of effort on the part of the ground crew to use it. However, it imposes a task on the pilot who must be able to land the helicopter on a relatively confined platform.

Configuration 5b (Ref. Figure 6)

This configuration is identical with 5a, except the tires are of the same size as those used in Configuration 2b, hence it has the same performance as that configuration. Due to smaller wheels, the towbar pull force is higher; however, considering other advantages, including smaller weight, it appears that this version is superior to 5a.

Configuration 6 (Ref. Figure 7)

This configuration, as shown in Figure 7, represents an attempt of employing the ground effect machine (GEM) principle for off-runway handling gear design.

The basic advantages and disadvantages of this design are similar to those of any GEM. Specifically, the GEM-gear requires extremely low tow forces, it is easily maneuverable, can adequately negotiate irregular soft or hard terrains, but it is undesirable from the point of view of dust recirculation and noise. In addition, special design considerations must be given to the power supply system and to the collapsible ground skirt.

Configuration 7 (Ref. Figure 8)

Configuration 7 as shown in Figure 8 is similar to Configuration 3, but in order to improve the maneuverability, it uses shorter tracks. Since short tracks have a tendency to dig-in (if the pitch axis is high above the ground as is the case in Configuration 3), this design brings the effective pitch axis down to the ground level. This is achieved by hinging the track buggy at two rather than at one axis. Two links, joining the buggy with the supporting structure are at an angle to each other. The effective pitch axis is where the line passing through the upper and lower hinges of one link intersects the line passing through the upper and lower hinges of the second link. The effective pitch axis is located at the center of the track contact area so that even pressure distribution exists in all cases, regardless of the direction of drag forces acting on the buggy when it is moved forward or aft.

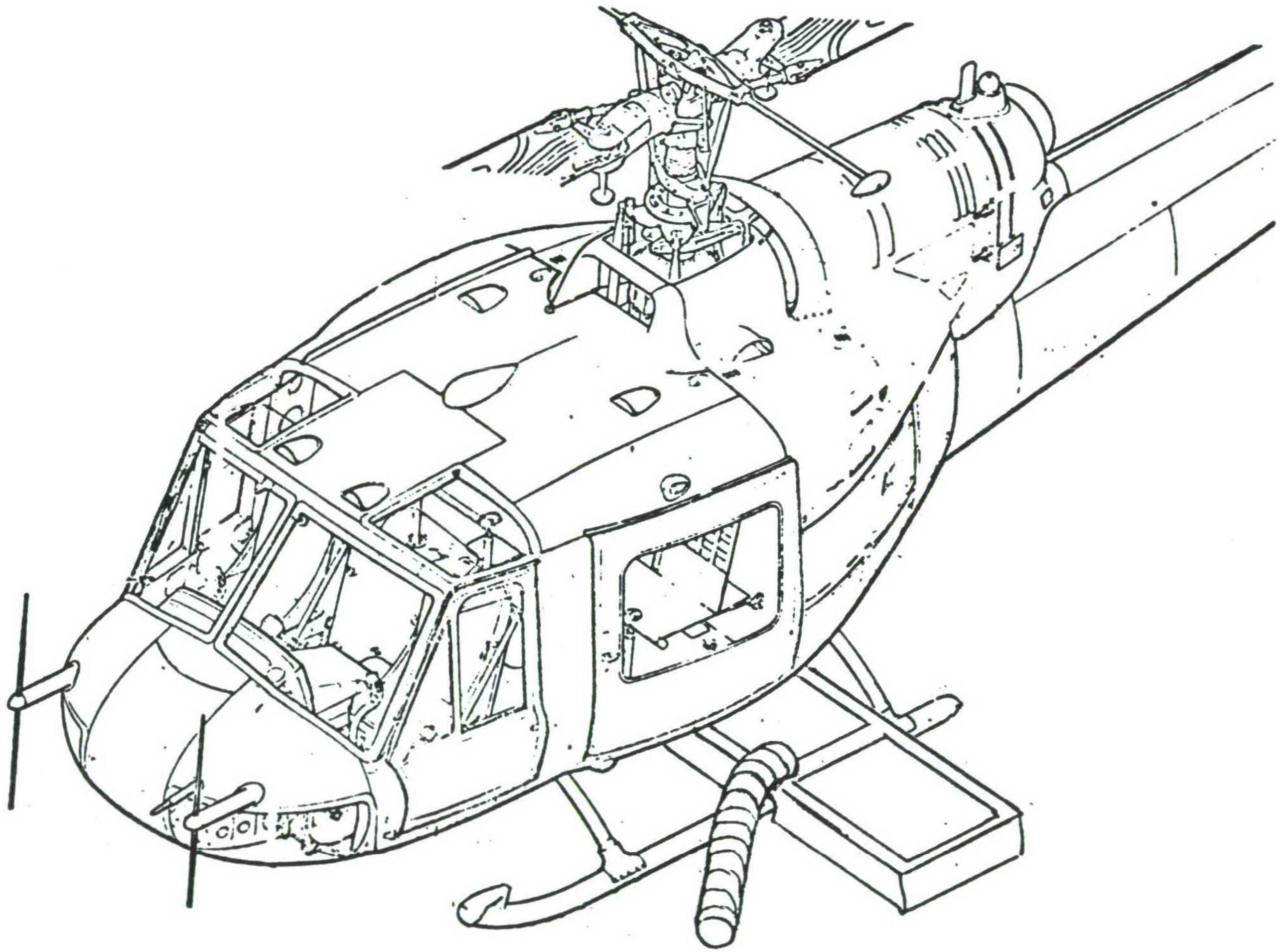

Figure 7. Off-Runway Handling Gear - Configuration 6.

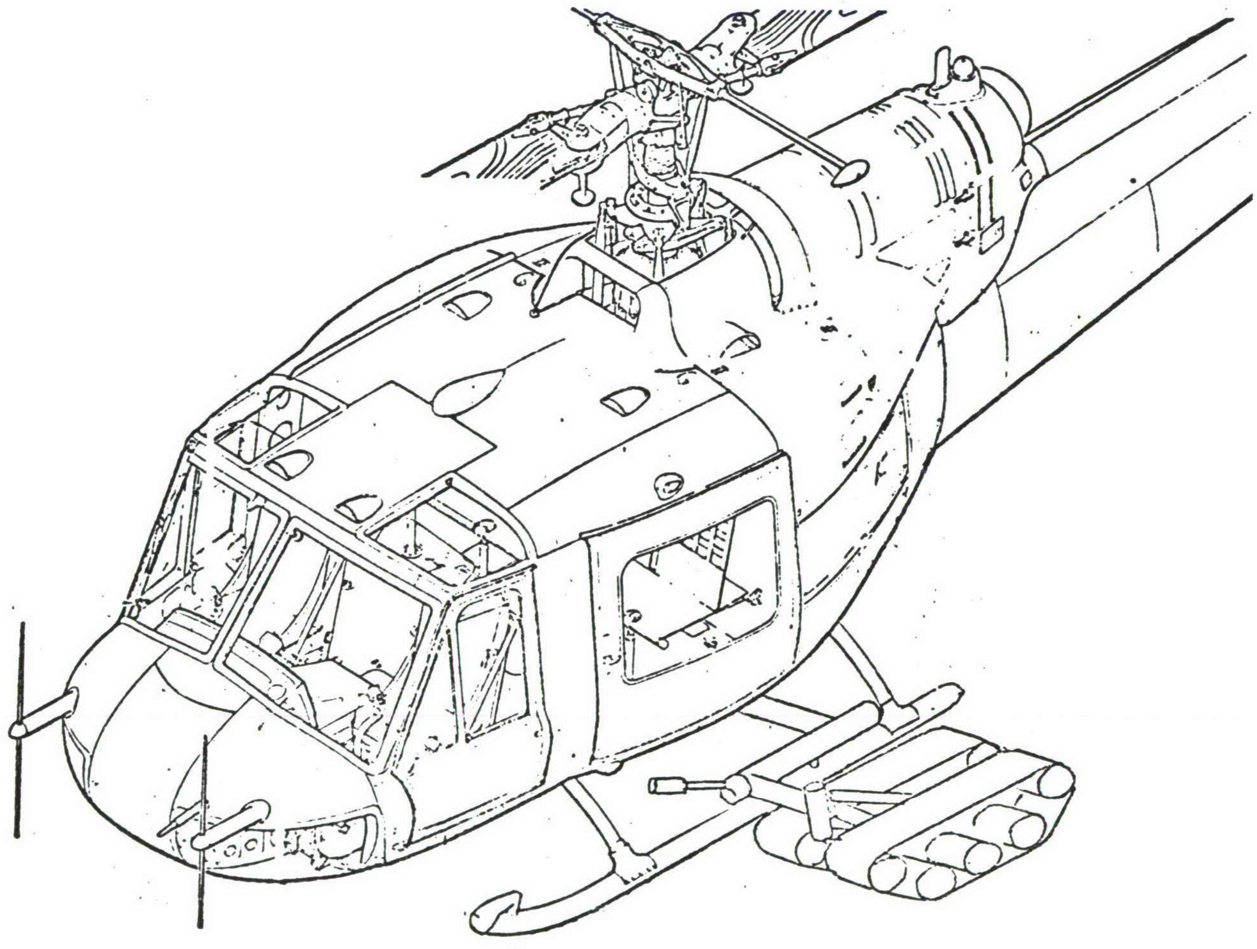

Figure 8. Off-Runway Handling Gear - Configuration 7.

The two links, supporting the buggy, are hinged at a structural member which is part of a parallelogram arranged to move the buggy up and down, with respect to the helicopter, by means of a hydraulic actuator. The remainder of the supporting structure is basically the same as that used in Configuration 3.

While somewhat more mechanically complicated this configuration has a definite advantage in that the buggies can climb over obstacles, without any tendency to dig in. In addition, the towbar pull force associated with this design is the lowest of all configurations considered herein.

The method of computations and the actual numerical values of the drawbar pull forces for each of the above configurations is as follow:

Calculations of Draw Bar Pull Forces

The drawbar pull calculations are based on test results obtained by the US Army Engineer Waterways Experimental Station, Vicksburg, MI as presented in Reference[1].

These test data as shown in Figure 9, reproduced from Reference 1, establish the relationship between P/W as a function of AMRB Numeric for fine grained soil.

Developed by the WES Army Mobility Research Branch, (AMRB) Numeric can be expressed as follows:

$$\text{AMRB NUMERIC} = \frac{W}{CI \times b \times d \times \sqrt{\Delta}} \qquad (1)$$

where W - wheel load, lb
CI - Cone Index
b - tire diameter, in
Δ - tire deflection, in/in, assumed as =0.25

The drawbar pull of the ground handling gear is estimated using max. gross weight of UH-1 helicopter of 9,500 lb and considering the cone index of the terrain of 40. Hence:

$$\text{AMRB NUMERIC} = \frac{W}{40 \quad \sqrt{.25bd}}$$

$$= \frac{W}{20\ bd} \qquad (2)$$

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[1] <u>A Vehicle Analysis for Remote-Area Operation,</u> Miscellaneous Paper No. 4-702, US Army Engineer Waterways Experimental Station, February 1965.

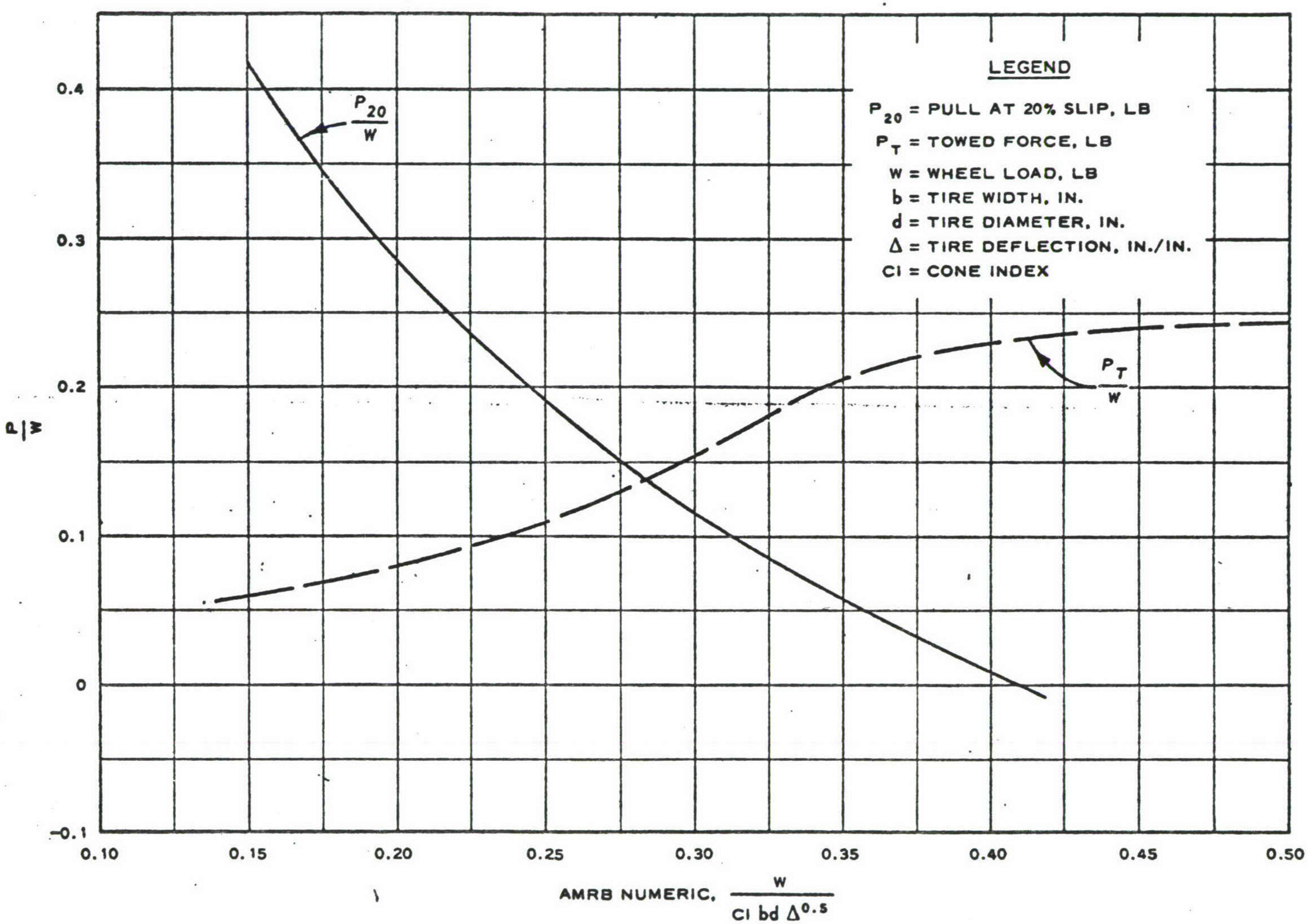


Figure 9. Tire Performance in Fine-Grained Soil

In calculations, the weight of the Handling Gear was taken at 800 lb, hence the operating max weight was taken at (9,500 + 800) = 10,300 lb.

Configuration 1

This configuration uses 2 tires 48 x 20.00-16.1 which take approximately 80% of the helicopter weight and 4 tires 16 x 14.50-6 which take the remaining load.

1. For the front 2 tires, AMRB numeric is:

$$\frac{.8 \times 10{,}300}{2 \times 20 \times 48 \times 20} = .215$$

From Figure 9, corresponding pull-to-weight ratio is:

$$P/W = .080$$

2. For the remaining tires, AMRB numeric is:

$$\frac{.2 \times 10{,}300}{4 \times 20 \times 16 \times 14.5} = .111$$

Using Figure 9, corresponding pull-to-weight ratio is obtained by extrapolation as:

$$P/W = .050$$

Hence the drawbar pull is

$$P_d = 10{,}300\ (.8 \times .08 + .2 \times .05) = 760 \text{ lb}$$

Configurations 2 and 5

Configurations 2 a and 5 a use four tires 48 x 20.00-16.1 and configurations 2b and 5b use four tires 38 x 20.00-16.1. All tires are assumed to be equally loaded.

1. For configuration 2a, AMRB numeric is:

$$\frac{10{,}300}{4 \times 20 \times 48 \times 20} = .133$$

Using Figure 9, the corresponding pull-to-weight ratio is

$$P/W = .055$$

Hence the drawbar pull is

$$P_d = 10{,}300 \times .055 = 565 \text{ lb}$$

2. For configuration 2b, AMRB numeric is

$$\frac{10{,}300}{4 \times 20 \times 38 \times 20} = .169$$

From Figure 9, the corresponding pull-to-weight ratio is given by:

$$P/W = .061$$

Hence the drawbar pull is

$$P_d = 10{,}300 \times .061 = 630 \text{ lb}$$

Configuration 3

This configuration uses 2 tracks, each having ground contact 12 in wide and 32 in long.

Terra tires have an average contact area

$$A = .3 \text{ bd}$$

on this basis, diameter of equivalent tire is

$$d = \frac{12 \times 32}{.3 \times 12} = 106 \text{ in}$$

Using the above as a criterion for the drawbar pull of the track

AMRB numeric is

$$\frac{10{,}300}{2 \times 20 \times 12 \times 106} = .202$$

Using Figure 9, the corresponding pull-to-weight ratio is given by

$$P/W = .075$$

Hence the drawbar pull is

$$P_d = 10{,}300 \times .075 = 770 \text{ lb}$$

<u>Configuration 4</u>

Configuration 4a uses six tires 29 x 12.00-16.1 and configuration 4b uses six tires 25 x 24.00-8R. All tires are assumed to take the same load.

1. For configuration 4a, AMRB numeric is

$$\frac{10{,}300}{6 \times 20 \times 29 \times 12} = .245$$

Using Figure 9, the corresponding pull-to-weight ratio is given by

$$P/W = .085$$

Hence the drawbar pull is

$$P_d = 10{,}300 \times .085 = 875 \text{ lb}$$

2. For configuration 4b, AMRB numeric is

$$\frac{10{,}300}{6 \times 20 \times 25 \times 24} = .143$$

From Figure 9, the corresponding pull-to-weight ratio is

$$P/W = .060$$

Hence the drawbar pull is

$$P_d = 10{,}300 \times .060 = 620 \text{ lb}$$

Configuration 7

This configuration uses four tracks, each having ground contact 15 in. wide and 22 in long.

Diameter of equivalent tire is

$$d = \frac{.15 \times 22}{.3 \times .15} = 73.5 \text{ in}$$

and AMRB numeric is

$$\frac{10{,}300}{2 \times 20 \times 30 \times 73.5} = .117$$

Using Figure 9, the corresponding pull-to-weight is obtained by extrapolation as:

$$P/W = .049$$

Hence the drawbar pull is

$$P_d = 10{,}300 \times .049 = 505 \text{ lb}$$

Dual Ground Handling Kit, Bell #204-050-200-5

This kit uses four Type III Aircraft tires 7.00-6 8 ply at 54 psi inflation pressure, 18 in dia and 6.8 wide.

AMRB numeric is

$$\frac{10,300}{4 \times 20 \times 18 \times 6.8} = 1.05$$

From Figure 9, the corresponding pull-to-weight ratio is obtained by extrapolation as:

$$P/W = .252$$

Hence the drawbar pull is

$$P_d = 10,300 \times .252 = 2,600 \text{ lb}$$

Selection of the Most Suitable Configuration

A comparative evaluation of various design features of the configurations described is presented in Table I. The comparison is based on pre-selected design and performance parameters which are considered most essential in operation of an off-runway handling gear. These parameters include drawbar pull force, clearance of the gear relative to the ground, time to load and unload the helicopter on or off the gear and gear weight.

Drawbar pull forces are those estimated on the basis of soil cone index of 40. As can be noted from Table I configurations 7, 2a and 5a have the lowest drawbar pull forces, whereas configurations 2a, 5a, 2b and 5b have the highest clearance factors. Estimated time of loading or unloading the helicopter on or off the gear is the lowest for configurations 5a, 5b, 1a and 1b. The total Handling Gear weight is the lowest for configurations 3, 7, and 5b.

The size and weight of each configuration is largely dependent on the requirement of the cone index 40 of the soil. However, the weight of some of the configurations could be reduced by approximately 10% to 20%, if new light weight tires and wheels could be utilized instead of the commercially available components upon which the weight estimate was based.

When all design factors were considered along with probable use, configuration no. 7 appeared to offer the best compromise and was chosen as the one on which to base further design efforts. It was also decided at this time to further increase the versatility of the unit as a test bed by providing a means of powering the tracks. Tests could then be conducted of either powered or unpowered tracks.

DESIGN

Stress and Loads Criteria

Since towing represents the most critical condition as far as loads and stresses are concerned which would be acting on various structural members of the handling gear, towing case was therefore considered as the most severe loading condition that can be imposed on the system. Although the loads and stresses on various structural members for the self-powered case will be lower, the overall system was designed for the most critical loading condition as shown below.

Loading Cases

1. All Three (3) Wheels Evenly Loaded.

   The design criteria for this condition are based on the following:

   Aircraft Max. Weight = 10,000 lbs

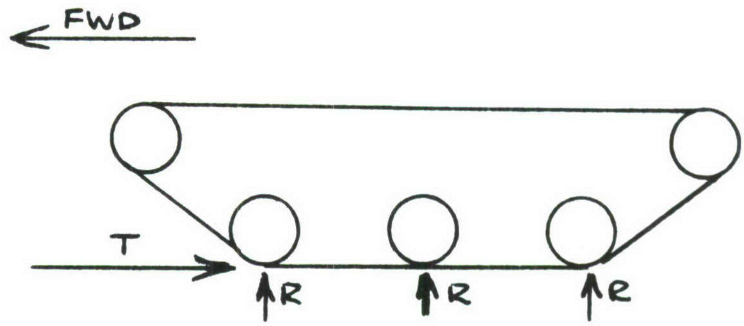
   Max. Towing Load (T) = 0.3 x 10,000 = 3,000 lbs

   Limit Factor = 2

   Safety Factor = 1.5

   Ultimate Design Factor = 2 x 1.5 = 3.0

a. Towing Forward (Even Surface)



$$3R = \frac{10,000 \times 2}{2} = 10,000 \text{ lbs}$$

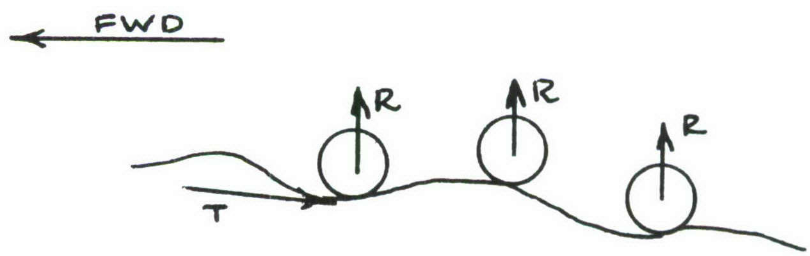
(Limit/Side)

$\therefore$ R/Wheel = 10,000/3 = 3,333 lbs

$$T = \frac{3000}{2} = 1,500 \text{ lbs}$$

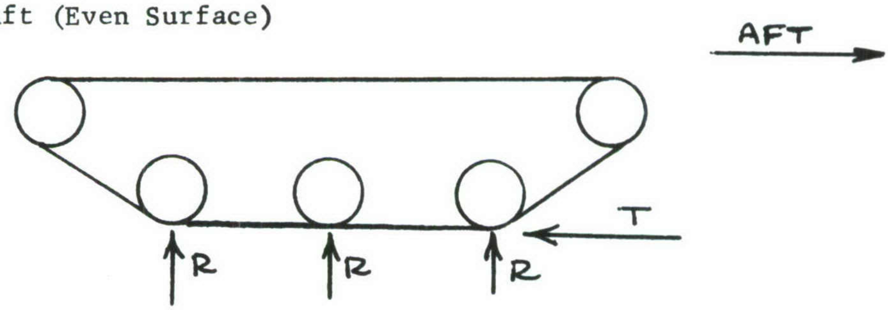
(Limit/Side)

b. Towing Forward (Rough Surface, 16° Incline)



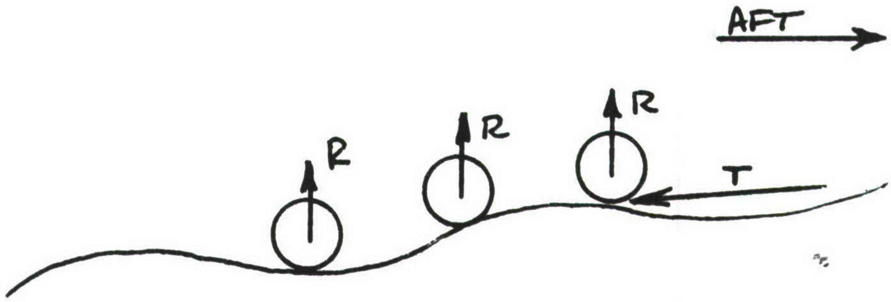
R & T the same as in a (1) above

c. Towing Aft (Even Surface)



R & T the same as in a (1) above

d. Towing Aft (Rough Surface, 13^{o} Incline)



R & T the same as in a (1) above

2. <u>Two (2) Wheels Loaded Only</u>

The design criteria for this condition are based on the following:

Aircraft Max. Weight = 10,000 lbs

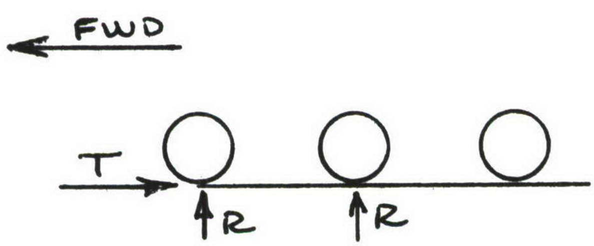
Max. Towing Load (T) = 0.3 x 10,000 = 3,000 lbs

Limit Factor = 1.5

Safety Factor = 1.5

Ultimate Design Factor = 2.25

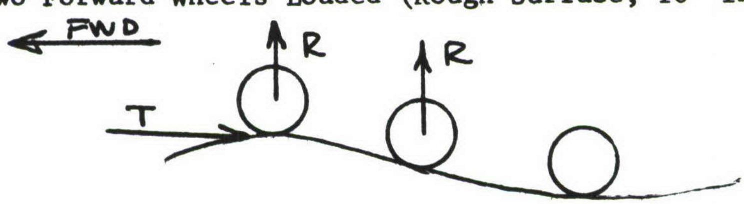
a. Two Forward Wheels Loaded (Even Surface)



$$R/Wheel = \frac{10,000 \times 1.5}{2 \times 2} = 3750 \text{ lbs (Limit)}$$

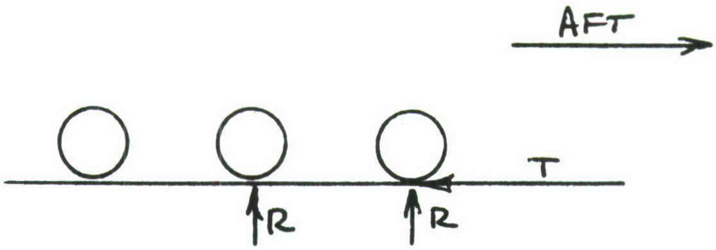
T = 1500 lbs (Limit)

b. Two Forward Wheels Loaded (Rough Surface, 16^{o} Incline)



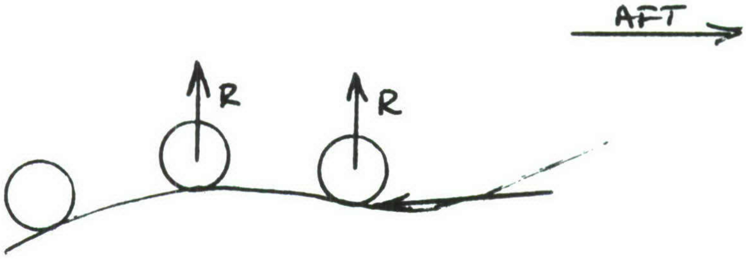
R & T the same as in b(1) above

c. Two Aft Wheels Loaded (Even Surface)



R & T the same as in b(1) above

d. Two Aft Wheels Loaded (Rough Surface 13^{o} Incline)



R & T the same as in b(1) above

3. Aircraft Attitude Variation

The design criteria for this condition are based on the following:

Aircraft Max. Weight = 10,000 lbs

Max. Towing Load (T) = 3,000 lbs

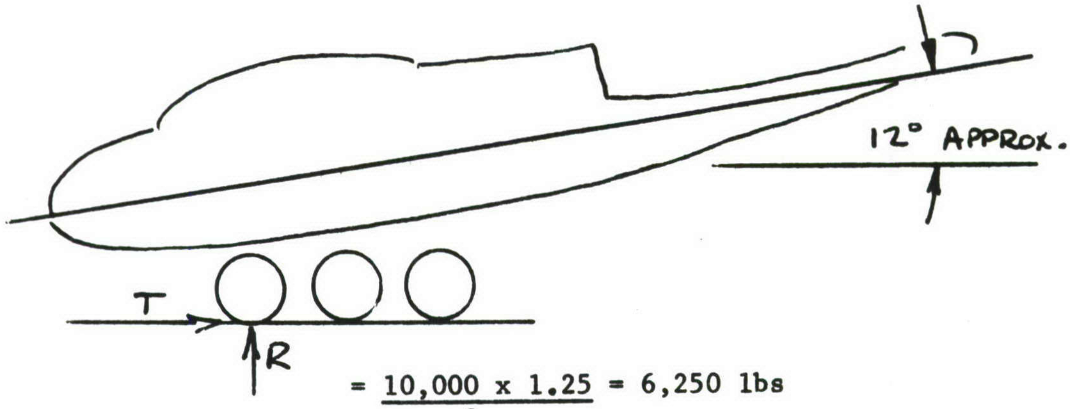
Limit Factor = 1.25

Safety Factor = 1.5

Ultimate Design Factor = 1.875

a. Aircraft Nose Down

Maximum nose up inclination of the handling gear is approximately 16^{o}. Aircraft nose down attitude can reach about 12^{o}. Therefore at least two sets of front wheels can take all the load.

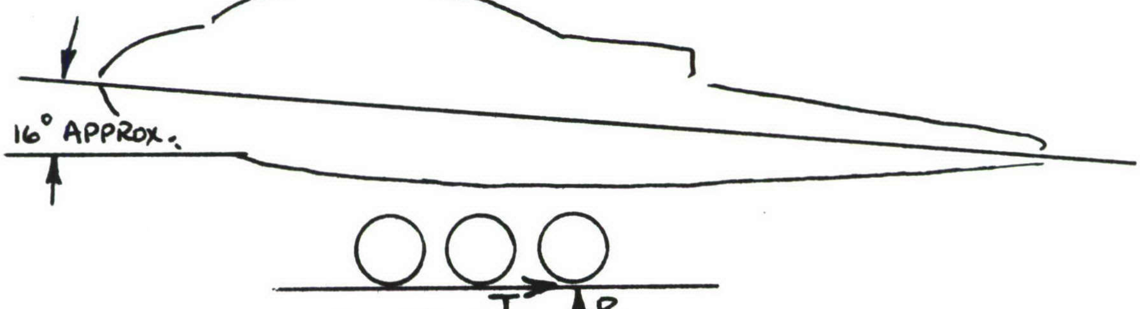


$$R_{(Limit/Side)} = \frac{10,000 \times 1.25}{2} = 6,250 \text{ lbs}$$

$$T_{(Limit/Side)} = 1,500 \text{ lbs}$$

b. Aircraft Nose Up

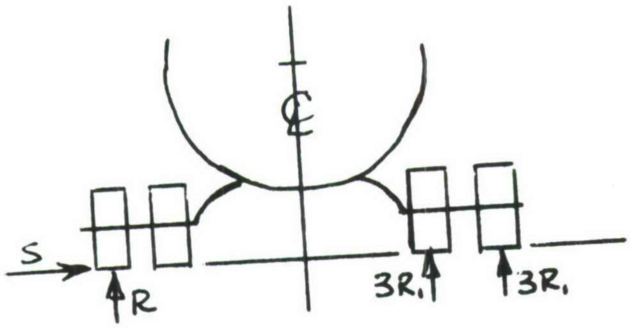
Maximum nose down inclination of the handling gear is approximately 13°. Aircraft inclination nose up may reach 16°, therefore aft wheels only will take all the load.

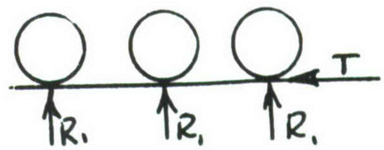


R & T the same as in c(1) above

4. Unsymmetric Loading

Since the handling gear is not designed to rotate about its longitudinal axis, therefore the design condition may exist where one set of wheels and the belt has to support approximately half of aircraft weight. In this case a limit factor 1.0 is used.





$$R = 2R_1 = \frac{W}{2x3} = \frac{10,000}{2 \times 3} = 1,667 \text{ lbs (Port Side)}$$

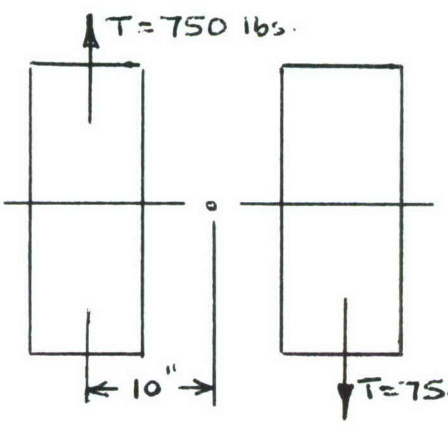
Also, maximum towing load of T = 3,000 lbs is considered. If the maximum towing load is inclined at 30^o to aircraft centerline (horizontal) then

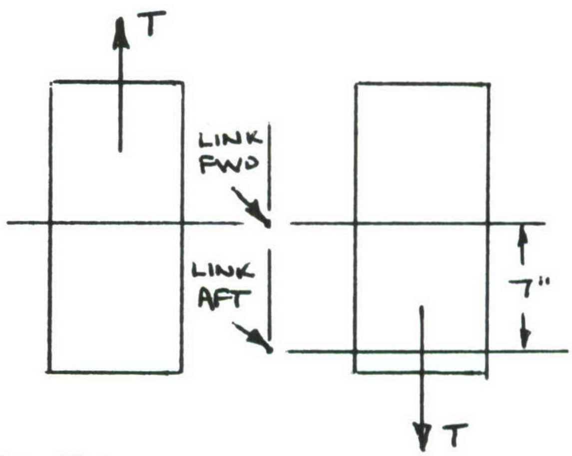
$$T = 3,000 \cos 30^o = 2600 \text{ lbs and the side force S is then}$$

$$S = 3,000 \sin 30^o = 1500 \text{ lbs}$$

5. Turning

For this loading case it was assumed that the handling gear was turning about the center point between the tracks of one "buggy". Since the maximum towing force is 3,000 lbs i.e. 1,500 lbs/side, the maximum tangential force acting on each track is 750 lbs. The limit factor for this loading case was assumed to be 1.0.





max. turning torque = 20 x 750 = 15,000 in. lbs.
side force in links 1 and 3 = 15,000/7 = 2142 lbs.

6. Loading Due to Self-Propulsion

The weight of the handling gear with the propulsion system is estimated to be 1000 lbs. Therefore total weight is

$$W_{max} = 10,000 + 1,000 = 11,000 \text{ lbs}$$

Using Reference (1), the AMRB numeric is computed as

$$\text{AMRB Numeric} = \frac{11,000}{2x20x30x73.5} = 0.125$$

Using Figure 9 of Reference (1) pull to weight ratio is given by:

$$P/W = 0.05$$

$$\therefore P = 0.5 \text{ x } w = 0.05 \text{ x } 11,000 = 550 \text{ lbs}$$

Assuming a maximum ground slope of 15% i.e. $8^{o}\ 32'$, the maximum thrust needed upon the incline is computed as:

$$T_{max} = 550 + 11,000 \sin 8^{o}\ 32' = 2185 \text{ lbs.}$$

Summary of Ultimate Loads and Stresses

Table II presents ultimate loads per side of the handling gear for the most critical links as shown in Figure 10 for the loading cases considered above.

Table III presents the maximum loads in the jack. It should be noted that the most critical loads in the jack correspond to loading cases a(1) and b(3) described above.

Table IV shows ultimate stresses in the selected components of the powered version of the system. This table also contains a comprehensive summary of other pertinent design criteria used in the design of the self-propeller off-runway handling gear.

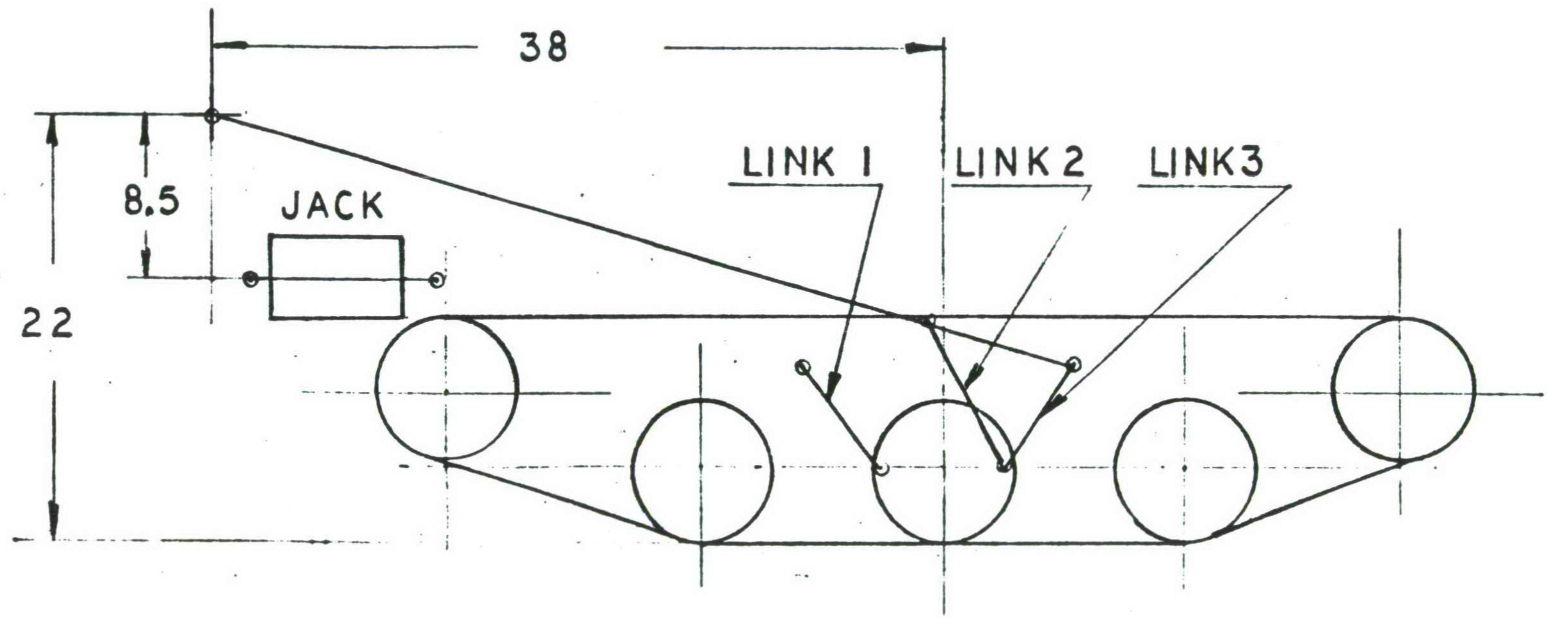


Figure 10. Link Identification

Propulsion System

A propulsion system is provided for each track unit. It consists of a gasoline engine-driven hydraulic system composed of: a fixed displacement pump to provide power for lifting the helicopter; a variable displacement pump to provide propulsive power and control; and a fixed displacement motor to provide torque to the tracks. The pumps are belt-driven from the engine, and the tracks are driven through a chain reduction system.

In operation, the engines run at a constant speed, with speed and directional control being effected by control of the variable displacement pump.

The detailed design of the unit is documented by LWL Drawing Nos. 050083001 through 050083103. These are available on request.

TABLE II. ULTIMATE LOADS IN THE MOST CRITICAL LINKS FOR THE LOADING CASES CONSIDERED

Loading Case	Link 1	Link 2	Link 3	R_B	Loading Ult - One Side
a(1)(R) a(1)(T)	-8250 +1580	0 +680	-9850 -1980	9850 2025	R_{side}=15000 lb T_{side}= 225 lb
a(1)	-6670	+680	-11830		
a(2)(R) a(2)(T)	-22500 +1580	+21000 +680	-18000 -1980	17250 2025	R_{side}=15000 lb T_{side}=2250 lb
a(2)	-20920	+21680	-19980		
a(3)(R) a(3)(T)	-8250 -1580	0 -680	-9850 +1980	9850 2025	R=1500 lb T_{side}=2250 lb
a(3)	-9830	-680	-7870		
a(4)(R) a(4)(T)	-5400 -1580	-4500 -680	-7500 +1980	10350 2025	R_{side}=15000 lb T_{side}=2250 lb
a(4)	-6980	-5180	-9480		
b(1)(R) b(1)(T)	-16900 +1580	-10700 +680	-7200 -1980	9100 2025	R_{side}=11250 lb T_{side}=2250 lb
b(2)(R) b(2)(T)	-32700 +1580	+33800 +680	-18600 -1980	27000 2025	R_{side}=1125 lb T_{side}=2250 lb
b(2)	-31120	+34480	-20580		
b(3)(R) b(3)(T)	-5050 -1580	-11250 -680	-6200 +1980	15750 2025	R_{side}=11250 lb T_{side}=2250 lb
b(3)	-6630	-11930	-4220		
b(4)(R) b(4)(T)	+4500 -1580	-11800 -680	-5625 +1980	14600 2025	R = 11250 T = 2250
b(4)	+2920	-12480	-3645		
c(1) c(2)	-31800 +12600	+30800 -20600	-13500 -3750	28300 22700	R_{side}=9350 lb

TABLE III. ULTIMATE LOADS IN JACK FOR CRITICAL LOADING CASES a(1) & b(3)

$(Ra)ver = (R)_{side}$ $\quad$ $(Ra)hor$ = Load in Jack

	1	2	3	4	4 + 6620*
Case	(R)side (Ra)ver	Arm	Moment about P+	Moment 8.5	Load in Jack (Ra)hor
a(1)	15000	38.00	570000	67000	73620
b(3)	11250	43.50	490000	57500	64120

TABLE I

COMPARISON OF CONFIGURATIONS

Figure No.	Config. No.	Ref. Dwg. No. C6188-7	General Features	Draw Bar Pull lb	Clearance Factor	Estimated Time of Loading or unloading, min.	Estimated Weights lb: Tires & Wheels or Tracks	Structure & Tow Bar	Hydraulics & Parking Brake	Total
1	1a	-001	1 piece unit, equipped with 2 front wheels 48" diameter x 20" x wide, at 10 psi & 4 rear wheels 16" diameter x 14.5" wide, at 10 psi	760	.53	1	405	450	75	930
2	1b	-001	same as 1a except rear wheels replaced by 2 tracks 22" long 6" wide	760	.95	1	430	450	75	955
3	2a	-002	2 piece unit, equipped with 2 front and 2 rear wheels, all 48" diameter x 20" wide, at 5 psi	565	1.60	3	670	400	90	1160
3	2b	-002	same as 2a, except all wheels 38" diameter x 20" wide, at 8 psi	630	1.27	3	530	400	90	1020
4	3	-003	3 piece unit, equipped with 2 tracks 32" long x 12" wide. Requires support at helicopter tail.	770	1.05	4	450	200	75	725
5	4a	-004	3 piece unit, equipped with 6 wheels 29" diameter x 12" wide, at 11 psi. Requires support at helicopter tail	875	.97	4	600	200	75	875
5	4b	-004	same as 4a, except wheels 25" diameter x 24" wide, at 8 psi	620	.83	4	685	225	75	985
6	5a	-005	1 piece unit, with helicopter landing on & taking off it, equipped with same wheels as in 2a	565	1.60	¼	670	300	None	970
6	5b	-005	same as 5a except wheels same as in 2b	630	1.27	¼	530	300	None	830
7	6	none	1 piece unit ground effect platform powered by pressurized air, supplied externally by flexible conduits	100 (curtain drag)	1.00	3	50	300	None	350
8	7	-006	3 piece unit, with 4 tracks, 22" long x 15" wide and mechanical linkage preventing skids to dig-in into the ground	505	.95	4	500	230	75	805

TABLE IV. PERTINENT DESIGN CRITERIA FOR SELF-PROPELLED OFF-RUNWAY HANDLING GEAR

PART NO	NAME	MATERIAL USED	CRITICAL LOADING CASE	CRITICAL PART	ACTUAL STRESS FOR ULTIMATE LOADS
050083004	Structure Support	Steel A1S1 4130 160000-180000 psi	Ultim Factor 3	in Joint of 3 Tubing	144000 psi
050083010	Arm Main.	" "	Ultim Factor 3	Jack Attach. Area	153000 psi
050083023	Structure Wheel Support	" "	Fwd C.G. + Belt Tension +	Near Att. of Fwd Link	120000 psi
050083016	Link Center	" "	Track Tilted Up Ult Factor = 3	Upper Fitting	60000 psi
050083030	Link Fwd	Alum 2024-T4	Side Load Case	Attach to Main Arm	51300 psi
050083031	Link Aft	Alum 2024-T4	"	Attach to Main Arm	45600 psi
050083033 050083042	Wheel, Standard and Aft	Alum 6061-T6	Belt Tension & Ultim Factor 3	Tooth Bar & Center Tubing	30000 psi
050083043	Base Propulsion Unit	Steel A1S1 4130 160000-180000 psi	Ult. Factor 3 & Max Motor Torque	Inner Fwd Leg	55000 psi
050083059	Tube Inter-Connecting	Alum 2024-T4	Ultm Factor 3	Through All Length	57500 psi
050083067	Structure Fwd	Steel A1S1 4130	Rough Handling	Center of Strut	160000 psi
050083077	Strut Side	"	3 People Can Sit on Strut		

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LIST OF SYMBOLS

W = Wheel Load lb.

CI = Cone Index

b = tire width in.

d = tire diameter in.

Δ = tire deflection in/in.

P_d = Drawbar Pull lb.

A = Contact area in.

R = Reaction Force lb.

T = Tractive Force or Towing Load lb.

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